ONTARIO STREAM FISHES HABITAT ASSOCIATIONS AND DERIVATION OF A SIMPLE HABITAT ASSESSMENT MODEL

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TABLE OF CONTENTS

LIST OF TABLES iii
LIST OF FIGURES iv
LIST OF APPENDICES v
ABSTRACT vi
RÉSUMÉ vi
INTRODUCTION 1
MATERIALS AND METHODS 2
Data Sources 2
Statistical Analyses 3
Habitat Suitability Matrix 4
Stream Habitat Assessment Model 5
RESULTS 6
Habitat Association Data 6
Cluster Analysis Of Habitat Associations 6
Temperature Preference Of Ontario Fishes 7
Species Clusters And Life History Characteristics 8
Habitat Suitability Matrix 9
Stream Habitat Assessment Model 10
DISCUSSION 12
ACKNOWLEDGEMENTS 15
REFERENCES 15

LIST OF TABLES

Table 1 Condensed habitat association variables and categories for 128 stream fish species at two life stages (adult and juvenile - 1+ and spawning - SP) were rated in terms of x = 0, 1 (1<= x <2), 2 (2<= x <3), 3 (=>3) where x = rating index 18

Table 2 Pearson correlations (r) among habitat association ratings for 128 Ontario stream fish species, within adult and juvenile associations (1+ to 1+), between adult-juvenile and spawning associations (SP in rows to 1+ in columns), and within spawning associations (SP to SP). Values of r greater than 0.3 are significant at a Bonferroni-adjusted P = 0.05 and are highlighted in **bold** 19

Table 3 Cross-tabulation and summary of species (rows) and habitat association (columns) clusters arising from the Orloci information metric analysis as a percentage of entries within the intersecting cells of row and column clusters with ones (zero values are shaded grey, values ≥80.0 are shown in **bold**). The number of species or habitat variables (categories and rating levels) included in each cluster is shown along with the habitat features 20

Table 4 Fish species belonging to the eleven species clusters obtained using the Orloci information metric and Q-test clustering of 1+ and spawning habitat association Ratings 21

Table 5 Linear regression models to predict final temperature preferendum (FTP) in freshwater fishes using alternate temperature reference end-points as the input variable and their order of use to estimate missing FTP values 22

Table 6 Cross-tabulation of number of species in clusters based on thermal preference, spawning or reproductive guild, a combination of thermal preference and spawning guilds, turbidity tolerance, and a summary of species maximum body length by species Cluster 23

Table 7 Character, species membership and species number of Ontario stream fish groups formed using a combination of thermal preference and spawning guilds 24

Table 8 Demonstration of the steps required to calculate habitat suitability matrix values for two fish groups, 1+ ColdHA2 and 1+ WarmHB**,. First, A) the species' association ratings are summed by habitat category within each fish group/life stage combination. Then B) the partial suitabilities are computed by dividing by the maximum sum within each habitat class. Finally, C) combinations of partial suitabilities from all three habitat classes are cross-multiplied to estimate the habitat suitabilities 25

Table 9 Recommended weights for life stages, stream thermal regimes and fish thermal guilds, and fish community objectives (fishery potential-F and species richness or biodiversity-S), using thermal and reproductive guilds, when pooling fish group suitabilities in an application of the stream habitat assessment model 26

Table 10 A demonstration calculation of weighted suitable area (WSA) for pre- and post-development scenarios on a 1000 m^2 reach of a cold water stream. The composite suitability is the weighted mean of suitabilities for all fish groups and life stages obtained using the weights recommended for a cold water stream in Table 9. The habitats are apportioned by habitat class, first flow type, then substrate within flow type, and finally by cover within flow type and substrate 27

LIST OF FIGURES

Figure 1 Dendrograms of the significant clusters for a) habitat associations (H) and b) species (S) obtained with the clustering method based on the Orloci information metric. The cluster axis scale is χ^2 (127 d.f. for habitat and 65 d.f. for species). The cluster numbers correspond to the row (S) and column (H) numbers in Table 3 and the species are identified in Table 4. Clusters above the p= 0.01 significance level are not shown 28

Figure 2 Bar graph showing the mean 1+ (hatched), mean SP (white), 1+ Cold×A2 (grey; salmonids and lampreys) and 1+ Warm×B (black; centrarchids, minnows, and bullheads) suitability values by habitat types. [In the three-letter habitat types, the first letter denotes flow - P (pool) or O (other); the second substrate – L (large), M (medium), or S (small); and the third cover – P (plant/algae), W (wood/substrate), or N (none)] 29

Figure 3 Star segment plots of the suitability of all 18 habitat types for all 16 fish group by life stage combinations. A key diagram, bottom right, identifies the habitat type combinations using the three letter labels described in Figure 2 30

LIST OF APPENDICES

Appendix 1 List of species by common and Latin names, included in this study 31

ABSTRACT

Minns, C.K. 2010. Ontario stream fishes habitat associations and derivation of a simple habitat assessment model. Can. Manuscr. Rep. Fish. Aquat. Sci. 2909:

Effective management of fish habitat depends on the consistent application of easy-to-use assessment tools. Stream habitat association data for Ontario fishes were analyzed and used to derive a habitat suitability matrix for use in a stream habitat assessment model. Cluster analysis of 128 species by 22 habitat variables (11 habitat categories, and two life stage groups, adults/ juveniles, and spawning) resulted in 11 significant clusters of both species and habitat categories. Flow type, cover, and substrate categories were more useful than depth as discriminators of species clusters. The absence of association observations (missing information) also had a role in forming clusters. Cross tabulations of species clusters with other ecological attributes (thermal preference, reproductive guild, turbidity tolerance, and maximum body size) indicated that a combination of thermal preference and the upper levels of Balon's hierarchy of reproductive guilds captured much of the patterning in the species clusters. The habitat associations were then used to estimate a habitat suitability matrix for 18 habitat types and 16 fish groups. A stream habitat assessment model was described and its usefulness demonstrated for habitat managers. Stream thermal conditions and fishery and biodiversity objectives provided criteria for weighting the contribution of different fish groups in specific habitat assessments.

RÉSUMÉ

Minns, C.K. 2010. Associations habitats lotiques-poissons de l'Ontario et obtention d'un simple modèle d'évaluation des habitats. Rapp. man. can. sci. halieut. aquat. 2909 :

La gestion efficace de l'habitat du poisson repose sur l'utilisation constante d'outils d'évaluation conviviaux. On a analysé et utilisé les données sur les associations habitats lotiques-poissons de l'Ontario pour obtenir une matrice de qualité de l'habitat à utiliser dans un modèle d'évaluation des habitats lotiques. L'analyse par groupes de 128 espèces selon 22 variables de l'habitat (11 catégories d'habitat et deux groupes d'âge selon l'étape de vie, adultes/alevins et frai) a donné lieu à 11 groupes importants de catégories d'habitat et d'espèces. Le type de débit, la végétation et les catégories de substrats étaient plus utiles que la profondeur comme critère de discrimination des groupes d'espèces. L'absence d'observations sur les associations (information manquante) avait également un rôle à jouer dans la formation des groupes. Les tabulations recoupées des groupes d'espèces avec d'autres attributs écologiques (préférence thermique, guilde reproductrice, tolérance à la turbidité et taille maximale du corps) ont indiqué qu'une combinaison de la préférence thermique et des échelons supérieurs de la hiérarchie de guildes reproductrices selon Balon reproduisait en grande partie la typification des groupes d'espèces. On a ensuite utilisé les associations d'habitats pour évaluer une matrice de qualité de l'habitat pour 18 types d'habitats et 16 groupes de poissons. Un modèle d'évaluation des habitats lotiques a été décrit et son utilité démontrée aux gestionnaires de l'habitat. Les conditions thermiques des milieux lotiques et les objectifs de pêche et de biodiversité ont fourni des critères pour pondérer la contribution des différents groupes de poissons dans les évaluations d'habitats précis.

INTRODUCTION

In Canada, fish habitat is protected by provisions of the federal Fisheries Act that bar "harmful alteration, disruption, and destruction (HADD)" of fish habitat and by a policy that mandates a guiding principle of "no net loss (NNL) of productive capacity of fish habitat" (cf Goodchild 2004). Unfortunately, detection and prediction of fish responses to habitat alterations are complex and challenging problems (Minns et al. 1996). As human development activities continue to disturb and destroy fish habitat, fish habitat managers should make the best possible use of available science to build assessment tools. Fish habitat managers and practitioners have called for new tools to assess the site-specific effects of development activities (Lester et al. 1997). Minns (1997) proposed a quantitative framework for assessing NNL and developed and implemented some defensible and practical assessment tools (Minns and Nairn 1999, Minns et al. 2001) and an operational tool, HAAT (Habitat Alteration Assessment Tool), for lake habitat particularly in the Ontario-Great Lakes Area of Fisheries and Oceans Canada.

This assessment framework is similar to the habitat, or resource, equivalency analysis approach emerging in the United States (Dunford et al. 2004). In equivalency analysis and previous approaches, habitat patches are assigned suitabilities between 0 and 1 according to the suitability of the patch type for the biotic target (species, life stage, group, etc.) and the product of patch areas and suitabilities are assumed to represent equivalent areas, providing a means to compare patches with different attributes. Assessment of net change of productive capacity is based on comparison of equivalent areas, as a surrogate for productive capacity, estimated for pre- and post-development scenarios. Canadian site-specific assessment tools have been developed mainly for lake habitats, primarily in Ontario, and streams have not received as much attention.

Links between fish community and habitat features in streams have been demonstrated extensively on reach, watershed, and landscape scales (cf American Fisheries Society Symposium 48, 2006; and, in particular, Stanfield et al. (2006) for salmonids in S. Ontario streams) demonstrating the role of factors across different scales. Approaches such as the index of biotic integrity (IBI) (cf Miller et al. 1988) have been widely used in streams to provide integrated measures of ecosystem and fish community health for longer stretches of streams and watersheds. Flow management has received much attention with a range of analytical tools emphasizing hydrologic metrics (Acreman and Dunbar 2004). These assessment tools are mainly focussed on larger scales. However, many habitat disturbances occur on a small scale (Quigley and Harper 2006 a, b) and site-specific assessment tools are needed for streams. Streams are a more frequent target than lakes for small-scale development activities such as culverts and stream crossings. The cumulative spatial impact of many small habitat modifications in streams may outweigh that of few much larger activities, such as mines or hydro-electric dams, that draw much regulatory attention. In Canada, few tools are currently used to assess small-scale changes to fish habitat apart from those focused in changes in hydrological regime (cf Rosenfeld 2003). Also, much of the stream fish ecology knowledge concerns salmonids in Canada, as in similar regions worldwide. For instance, in Ontario, the Ontario Stream Assessment Protocol (OSAP, Stanfield 2005) has been primarily used for extensive surveys in salmonid streams. Like IBIs on larger scales, site-specific assessment tools that consider all fish species in an area are needed given the rising concerns for conservation of ecosystem health, biodiversity, and species-at-risk (Chu et al. 2003). The overall goal of this paper is to develop a simple site-specific habitat suitability assessment tool for streams.

A site-specific stream assessment tool must cover the range of habitat types and the fish species assemblages present in a region. Such models should be simple for three main reasons: 1) the information available on fish habitat requirements is often limited and much of what is known is fragmentary and anecdotal; 2) the model must be readily understood and easy to ,implement, and 3) collecting the information needed for its application should be simple, quick, and cheap. Suitability models have been developed for well-studied species such as salmonids [e.g., juvenile Atlantic salmon by Hedger et al. (2005)] but the habitat associations of many Canadian stream fish species are poorly known (Minns 2001, Portt et al. 1999). Grouping species based on ecological characteristics and pooling their limited habitat association data provides a way to derive a habitat suitability assessment model that allows community needs to be considered during assessment. Temperature is a dominant factor in the ecology of fishes (Magnuson et al. 1979) and strongly influences local occurrences of fish with different thermal preferences in Ontario streams (Chu et al. 2008). As stream thermal regimes can vary considerably (Stoneman and Jones 1996) any habitat assessment model must consider the thermal preferences of fish species. To address this range of issues, the specific goals of this study were to 1) assess inter-specific similarities in stream habitat associations among the many fish species occurring in Ontario watersheds, 2) examine the relationship between patterns in habitat association and life history and ecological characteristics of fish species as a basis for grouping species, and 3) use those results to guide derivation of a habitat suitability matrix for use in a stream habitat assessment model, giving particular attention to thermal preferences.

MATERIALS AND METHODS

DATA SOURCES

Portt et al. (1999) reported the results of an extensive literature review of stream habitat associations of fishes present in the Ontario Great Lakes basin; association is taken here to include both selection and observed occurrence with a habitat. Using published literature observations and commentaries, they rated degree of association for a range of habitat categories within classes for depth, substrate, cover, and flow type for adults and juveniles combined (1+) and for spawning (SP). Note the flow type class here refers to hydraulic habitat type and not to discharge. The review was also subjected to external peer review to assess the consistency and completeness of both the literature review and the ranking of associations. Adult associations were reported far more often than juvenile ones and when both were reported they were often similar; the adult and juveniles are identified by the short form 1+ hereafter. Young-of-year habitat associations were not reported but might be expected to be similar to those for spawning in many instances with fry staying near to where they hatched; the spawning stage is identified by the short form SP hereafter. Associations which were rated as low, medium, or high (null was the default value), were assigned the value of 1, 2 or, 3, respectively (nulls were assigned as 0, signifying no association). As the original species by life stage by habitat category matrices were sparsely populated (e.g., Table 9 in Portt et al. 1999), the number of categories for each habitat variable or axis, (depth, substrate, cover, flow type) was reduced by combining some of the categories. Where ratings for the original categories differed, an average value was computed within the new category. In most instances, the original categories had similar entries and hence the condensation involved little distortion of original data. Portt et al. (1999) reported depth association in five categories (0-20 cm, 21-60 cm, 61-100 cm, 101-200 cm, and 201+ cm) and here they were reduced to three categories: 0-60 cm, 61-100 cm, 101+ cm. Substrates were reduced to three categories from nine: large (hard-pan clay, bedrock, boulder, cobble, rubble), medium (gravel, sand), small (silt/clay, detritus). Three categories for cover were defined – plant (vegetation, algae), wood/substrate (wood, substrate, overhead), and no cover. As association with no cover was not considered in

Portt et al. (1999), a synthetic means was used to estimate fish species selection for no cover based on reported associations with other cover types. This lack of attention to selection for no cover reflects the prevailing predisposition among fish biologists to always assume the presence of, and association with, some form of cover. In any stream reach, patches will always occur where all cover is absent and, hence, preference for no cover must be estimated. In this study, a lack of reported association with cover types was assumed to indicate an implicit selection for no cover. No cover was computed here as a function of the other cover categories:
No Cover = Integer ((Integer((9- sum(Plant, Substrate, Wood))/3)+(3-Max(Plant, Substrate, Wood))/2))
This function weighted both the diversity and strength of reported cover associations. Grandmottet (1983) used a similar approach to express the flexibility of habitat preferences in European freshwater fishes. Four flow type categories (pool, riffle, run, and rapid) in Portt et al. (1999) were reduced to two: Pool, and Other. Other ecological information for the fish species was derived from the compilation of Coker et al. (2001) which assembled literature data on life history, spawning, food habitat, ecosystem occurrences, and exploitation for many of Canada's freshwater fishes.

STATISTICAL ANALYSES

A preliminary Pearson correlation analysis of habitat ratings by species was undertaken to determine if recurrent patterns of habitat association were present among and between the main habitat axes – depth, substrate, cover, and flow. To test the level of significance for correlation coefficients, a Bonferroni correction for multiple comparisons was applied. The correlation analysis required the assumption that the association ratings on an interval scale of 0 to 3 represented a continuous linear scale.

A cluster analysis of habitat associations by fish species was undertaken to see if either habitat categories or species/life stages aggregated into distinct groups. Groupings were then associated with life history and ecology characteristics, providing a basis for fish groups in a habitat suitability matrix. After eliminating a few species with no association ratings, condensed association data were assembled for 128 species (Appendix 1) in 11 habitat categories (Table 1) for each life stage (1+ and SP). The fish species by habitat association matrix was recoded to ensure that adjacent association ratings of habitat categories would tend to stay together when clustered (i.e., low with medium and medium with high). Each habitat category value was recoded as three variables as follows: null (0,0,0); low (1,0,0), medium (1,1,0) and high (1,1,1) with half values rounded down. This meant the number of habitat variables increased to 66 with 11 habitat classes in two life stage groups (1+ and SP) each with three levels. The binary data matrix was clustered using an information theory metric (Orloci 1972) and the application described by Minns (1989). The cluster metric approximates a χ^2 distribution and the testing for combining prior groups follows Cochran's Q-test (cf Kelso and Minns 1996). The clustering proceeds iteratively by pooling the most similar pair of binary matrix rows at each step and measuring the change in the information content as a χ^2 value. Each step reduces the number of groups by one. In the later stages of clustering, pairs of groups are pooled that have significant χ^2 values and these pairings represent significant splits, or partitions, within the binary data matrix. The clustering is complete when only one group remains. The statistical significance level was set at P=0.01 for acceptance of clusters. Both species and habitat associations were clustered and the data matrix was reordered by cluster membership on both axes to aid interpretation. The reordered binary matrix was summarized by computing the percentage of non-zero values in intersecting blocks of entries arising from significant species and habitat clusters. This clustering approach emphasizes the role of non-null data and provides an objective end-point for identification of clusters.

Post-hoc analyses of the fish species clusters obtained were used to examine fish species habitat associations in conjunction with life history characteristics, (e.g., thermal preference, spawning guild, turbidity tolerance, and maximum body length) (Coker et al. (2001)). Coker et al. (2001) classified thermal preference for fish species into five groups: cold, cold-cool, cool, cool-warm, and warm. The cold-cool and cool-warm species were reassigned after further analyses into one of three main thermal groups: cold, cool, and warm because the number of species in the cold-cool group was small and the assignments in the cool-warm were often uncertain.

Simple relationships are expected among various temperature reference points in fishes (Beitinger and Bennett 2000, Beitinger et al. 2000) and these reference points should provide a basis for objectively classifying fish species into thermal groups or guilds. Values on various temperature reference points for North American freshwater fishes were assembled from literature. Final temperature preferenda (FTP, n=32 data points) were assembled from Wichert and Lin (1996) and Wichert (pers. comm.. Gartner-Lee Ltd., Toronto, Ontario). Optimum preferred temperatures (OPT, n=53), usually optimum growth temperature, were obtained from Wismer and Christie (1987) and Danzmann et al. (1991). Incipient upper lethal temperatures or their equivalent critical maximum temperatures (IULT or CMT, n=60) were from Beitinger et al. (2000). Coker et al. (2001) compiled a list of preferred temperatures (PT, n=64) and Eaton and Scheller (1996) used field observations of fish in streams throughout the United States to estimate maximum temperature tolerance (MTT, n=40). These sources often had more than one type of temperature metric but the references indicate the primary sources for each datum type. These sources provide detailed definitions of the various temperature metrics. Two groups of metrics were assembled; those that refer to upper temperature tolerance limits (CMT, IULT, and MTT) and those that refer to a midpoint preferred temperature that is selected for living (FTP and PT) or that optimizes growth (OPT). Linear regressions models were developed between FTP and other temperature metrics. The models were then used to estimate final temperature preferenda (FTP) values for as many of the Ontario stream species as possible. Cut-off temperatures between cold-cool and cool-warm were identified based on discontinuities in the cumulative frequency of FTP values. The estimated FTP values were used to update the assignments of Ontario fish species by thermal group.

To test the utility of life history and ecological characteristics as predictors of fish species clusters, clusters were cross-tabulated by characteristic groupings. In the case of maximum body length, an analysis of variance was performed with species clusters as a treatment and $\log_{10}$-transformed lengths as the variable assessed. Based on these comparative analyses, fish species were grouped using selected criteria.

HABITAT SUITABILITY MATRIX

Once the fish groups were determined, the derivation of a stream habitat suitability model followed an approach similar to that described for lake species and habitats in Minns et al. (2001). Within each fish group and life stage, the habitat association ratings for each habitat category were summed across species. The sum was assumed to represent the available aggregate preference of all species in the group. This provided a way to overcome the incompleteness of the original and condensed association rating data in many species. Then, the sums were divided by the maximum across the categories within each habitat variable (i.e., flow, substrate, or cover) by species group and life stage. This ensured that the maximum partial suitability by category within each habitat variable had a value of one. This helps avoid the problem of obtaining very low suitabilities when cross-multiplied across habitat variables.

Finally, partial suitabilities from all habitat classes were cross-multiplied (substrate category by cover category by flow category) and yielded habitat suitabilities for all habitat category combinations by fish group and life stage. The orthogonal approach, treating each habitat class as being independent, was justified by the overall absence of strong correlations among the habitat association ratings that indicated independence among the main habitat axes. Alternate schemes such as taking the average or minimum of the partial suitabilities tended to produce results similar to cross-multiplication.

STREAM HABITAT ASSESSMENT MODEL

A habitat assessment model requires at least three components:

- A habitat suitability matrix of habitat types by biotic components,
- A system of weights for biotic components allowing consideration of specific ecosystem features, the characteristics of the local species pool, and management objectives in each application, and
- A well-defined protocol for mapping areas by habitat type at the application site.

The method for developing the suitability matrix was outlined above. The basis for the system of weights will be described in the Results section below. The OSAP (Stanfield 2005), or similar standardized approaches, can be used to obtain the required mapping of habitat areas at an application site.

Habitat assessment models based on habitat equivalency use suitability matrices to compute weighted suitable habitat area (WSA), a measure of suitable habitat supply for fish assemblages. For example, a stretch of stream can be mapped to estimate the area of patches by habitat type. Each habitat type has attributes based on combinations of the categories within the habitat variables flow type, substrate, and cover. The product of area and suitability is summed over all habitat types (I=1…N) giving $WSA_{\cdot J}$ ($= \Sigma(A_I \times S_{IJ})$) where A_I is the area of a homogenous habitat patch of type I and S_{IJ} is the suitability of habitat type I for fish component (group/life stage) J. For instance, if a 100 m^2 stream habitat area (e.g., a pool with medium-sized substrate and no cover) has a suitability of 0.5 for a particular fish group, then WSA is 100 x 0.5 or 50.0 m^2. Calculation of WSA for all fish groups in a stream reach with many patches with different habitat types requires that a single composite suitability be applied for each habitat type. A composite suitability, $S_{I\cdot} = \Sigma(W_J \times S_{IJ})$, is computed as the weighted sum of suitabilities for habitat type J, where J=1 to M and M is the number of fish components. The weighted suitable area for all habitat types based on the composite suitabilities is $WSA_{\cdot\cdot}$ ($= \Sigma(A_I \times S_{I\cdot})$). In a development application, the WSA values can be determined for pre- and post-development scenarios within a fixed assessment footprint using the same weights for both scenarios. If the post-WSA is less than the pre-WSA, a net loss of productive capacity of fish habitat is presumed.

Rules for weighting biotic components are outlined using stream thermal regime, known habitat constraints on population dynamics, and fish community management objectives. The calculation of biotic component weights is demonstrated as part of an illustrative simple case study comparing weighted suitable area in pre- and post-development scenarios in a reach of a cold-water stream. Other non-habitat factors influencing the assessment of net change of productive capacity are noted.

RESULTS

HABITAT ASSOCIATION DATA

Zero entries still dominated the condensed habitat association matrix with depth having the least information (Table 1). Adult-juvenile (1+) data were more common than spawning (SP) data. Pearson correlations among habitat association ratings were mostly non-significant (i.e., only correlations above 0.3 were significant at a Bonferroni-adjusted probability level of 0.05) (Table 2). More than 50% of the 1+ to 1+, SP to SP, and 1+ to SP pairwise correlations were less than 0.164, 0.146, and 0.119, respectively. The distributions of correlation values within life stages were comparable and correlations between life stages were generally lower. All the correlations >0.51 and <1 arose between no cover and the other cover classes due to the method used to estimate no cover association based on other cover associations. Spurious correlations of 1.0 were obtained for some depth categories and arose as an artefact of how the depth range data were condensed from Portt et al. (1999); for 1+ the ratings for 0-60 cm and 61-100 cm were the same in all species and, similarly for SP, ratings for 61-100 cm and 101+ cm. In general, low correlations indicated that habitat associations within each habitat variable were independent and supported the use of the multiplicative formulae used to compute habitat suitabilities as in Minns et al. (2001).

CLUSTER ANALYSIS OF HABITAT ASSOCIATIONS

The cluster analysis using the Orloci information metric produced 11 significant (probability level <0.01) clusters, or matrix subsets, for both the fish species (S) and habitat parameter (H) axes of the data matrix (Figure 1). The final pairs of clusters had significant χ^2 values of 573.89 (d.f.=127) and 479.51 (d.f.=65) for habitat categories and species, respectively. The least significant pairs of clusters ($P<0.01$) had χ^2 values of 177.24 and 101.22 for habitats (H5 and H6) and species (S10 and S11), respectively. Below the significance threshold the next χ^2 values were 154.23 (P=0.05) and 87.26 (P=0.04) for habitats and species, respectively. Further down the cluster tree, χ^2 values dropped to complete non-significance (P=0.99) at 92.79 for habitats and 42.74 for species.

The clusters of habitat association categories (Table 3) showed that the different rating levels (low, medium, and high) of most habitat categories clustered together as expected but for the no cover category where the low level was separated from the medium and high values, which stayed together. The 1+ and SP habitat categories mostly stayed separate until the final stages of the clustering except in habitat cluster H7 where 1+ association with depths >100 cm paired with SP association with small substrate. The depth associations contributed little to the clustering of fish species as they mostly entered in the final stages of the grouping. Otherwise, within life stages there was a greater intermingling among substrate, cover, and flow type classes, e.g., cluster H3 with small substrates and, low or no cover in pools, and clusters H2 (1+) and H11 (SP) with large and medium substrates and the other (non-pool) flow type. Clusters like H9 and H5 may be determined by the absence of habitat association data as indicated by the larger number of fish groups with zero entries (indicative of a lack of observations) in those habitat clusters (Table 3). The separation of most life stage information into distinct habitat clusters provided a rationale for assessing 1+ and SP habitat associations separately in a suitability matrix.

The species clusters were very mixed groups and did not immediately appear to readily follow any traditional groupings such as taxonomy (Table 4). For example, cluster S1 contained

both lampreys and madtoms, and cluster S11 included both brook trout and smallmouth bass, mixing both cold and warm water species. Cluster S10 contained many cool and warm water species familiar to Ontario fishers. Given that species may share physical habitat preferences but succeed by exploiting those stream habitats in different regions or in different thermal regimes, possibly to minimize trophic interactions, the mixtures of species within groups were not surprising.

Cross-tabulation of the significant species and habitat category clusters and calculation of the percentage of non-zero values in each cluster cell showed how the habitat associations helped shape the species clusters (Table 3). However, few patterns were readily discernible. The absence of data values was more prevalent in the first group of species clusters (S1 to S7 in Figure 1) compared to the second group (S8 to S11). Within the first group, S2 was strongly determined by H5 (the 1+ association with plant cover) and S3 by H3 (the 1+ association with small substrate and low or no cover in pools. The absence of association data was denoted by zeroes in the binary data matrix so that some clustering of species and habitat associations were likely driven by the incompleteness of ecological knowledge about many species' habitat associations and the unlikelihood that species absences are noted at sites within regions where they occur. Without intensive investigations, it is difficult to distinguish absence of data and absence of association. The approach to developing the habitat suitability matrix shown below should help limit the impact of data insufficiency.

These cluster results alone did not suggest a basis for forming fish groups when developing a stream habitat suitability matrix. The mixing of species with differing temperature preferences within species clusters highlighted to need to consider life history and thermal preference when forming fish groups for a habitat suitability matrix. Any classification scheme must have some resonance with the current understanding among fish ecologists. Nonetheless, the ratings data and the cluster analysis did provide a synthesis of available knowledge and informed the development below of a suitability matrix. The pooling of species association data into groups makes the best use of available data in the development of a model and assessment as was done for fish habitat associations in lakes by Minns et al. (2001).

TEMPERATURE PREFERENCE OF ONTARIO FISHES

Linear regression models significantly predicted final temperature preferendum (FTP) from other temperature reference points (Table 5). Correlations (r) ranged from 0.63 to 0.95 with sample sizes from 22 to 32. Preferred temperatures (PT, OPT) were typically 2-6°C below FTP values while upper limiting threshold temperatures (IULT, CMT, MMT) were typically 10-15°C higher than FTP values. These regression models were used, with precedence assigned to the models with the highest correlation, to estimate missing FTP values when other temperature metrics were available. Inspection of the cumulative frequency of all FTP values (n=89) indicated well-defined discontinuities at 18.5 and 25.5°C, marking the boundaries between cold, cool, and warm categories. Species with FTP values were assigned to one of the three thermal groups. Species previously classified as cold, cool, or warm by Coker et al. (2001) but lacking temperature endpoint data, were left in those original groups. The remaining unclassified species (13 out of 128) were reassigned based on the thermal class assigned to taxonomically similar species. Most of Coker et al.'s (2001) cold-cool species were assigned to the cold group while cool-warm species were evenly split between cool and warm groups. Fewer species (25) preferred cold waters while the numbers in the cool and warm groups were similar (i.e., 53 and 50, respectively). These results allowed thermal preference to be included in the life history attributes used to assess the Orloci species clusters.

SPECIES CLUSTERS AND LIFE HISTORY CHARACTERISTICS

The species clusters were cross-tabulated with species' thermal preferences and spawning guilds, with species' turbidity tolerances, and summarized using the maximum body length of fish species. The objective in these analyses was to identify species classifications based on life history characters that captured as much as possible of the information in the cluster analysis whilst retaining an acceptable level of concordance with received understanding of inter-species associations and assemblages in streams. For example, most fish biologists expect to see thermal segregation of species whereas the species clusters had mixed thermal preferences.

The species clusters were partially separated by thermal preference (Table 6). The coldwater species were concentrated in clusters S4, S5, and S7 and absent from five clusters. The cool and warmwater species were broadly distributed with higher frequencies in clusters S3, S4, S6, S8, and S10. Species clusters were also partially separated according to the higher levels of Balon's (1990) hierarchy of spawning guilds (Table 6). The first level of Balon's hierarchy separates guarder (B) and non-guarder (A) species. The second level separates broadcast spawners (A1) from hiders (A2) in the non-guarder species pool and separates nesters (B2) from substrate choosers (B1) within the guarder species. Further sublevels relate to specific habitat selections or behaviours. Most Ontario stream species are non-guarders and open substratum spawners. The lithophils were concentrated in clusters S4, S5, and S6; the phytophils in cluster S8 and the psammophils in clusters S3 and S4. The non-guarder brood hiders were spread across four clusters (i.e., S1, S4, S5, and S6). Among the guarders, most species were nest spawners with speleophils concentrated in clusters S1, S2, and S10, and lithophils concentrated in clusters S9 and S10. Both thermal and reproductive guilds capture some elements of the cluster patterns.

The average maximum length of species varied across clusters (Table 6). One-way analysis of variance on $\log_{10}$ of maximum fish length (mm) by species clusters indicated that they were significantly different among cluster means ($P<0.001$). Clusters S5, S6, and S10 were dominated by larger species whereas clusters S2, S3, and S9 were dominated by smaller species. In most groups the fish size range was relatively high (coefficients of variation ranged from 8.6 to 12.8 %), making it difficult to discern a size classification that might be useful for grouping species.

The turbidity tolerance of many species was not known or recorded (Table 6). Those species with known status showed some separation among the clusters. Intolerant species were most common in clusters S1, S2, S6, and S7. The tolerant ones were most frequent in clusters S4, S8, S9, and S10. It might be expected that turbidity tolerance of fish species would be related to their preferences for smaller substrates which make up much of the turbidity in streams but such a linkage was not strongly indicated (Table 6). A more complete assessment of turbidity tolerance must await the determination of tolerance for many more species.

Of the four ecological characteristics assessed, thermal and spawning guilds showed the most association with the species clusters based on habitat selections. The combination of thermal preference with the first two levels of the hierarchical spawning guild classification showed greater agreement with the species clusters (Table 6) compared with each factor taken singly. When the number of species was low in some instances, some spawning groups were combined. The B1 and B2 spawning groupings were pooled into B within the three thermal groupings and the A1 and A2 groupings were pooled into A for warm water species. The Cool×A1 and Warm×A groups were mostly distributed across the species clusters although it

should be remembered that much of the separation of species clusters may be due to incompleteness of habitat selection knowledge. The only B1 (guarder/substrate choosers) species prefers warm water and one species belonged to Warm and A2.

The fish species from eight fish groups obtained via thermal and spawning guilds have memberships familiar to Ontario fish biologists (Table 7). For example, the Cold×A1 group consists mainly of cold water species more often encountered in lakes than in streams; the Cold×A2 is a mixture of salmonids and lampreys; and the Cold×B group consists of sculpins and sticklebacks. The Cool×A1, Warm×A, and Warm×B groups have large numbers of species. The Warm×B group contains many centrarchids. The darters are spread among the three Cool groups reflecting their diversity of life histories (Paine et al. 1982). The combination of thermal and spawning guilds captured much of the information represented in the species clusters and provided species groupings familiar to fish biologists and habitat managers. Maximum size and turbidity tolerance were not considered further. These 8 thermal-spawning guilds were used as the basis for the habitat suitability matrix in the assessment model.

HABITAT SUITABILITY MATRIX

A habitat suitability matrix was computed for each combination of the 8 fish groups and 2 life stages (1+ and SP). Depth was excluded as values were the same for two of three categories within each life stage and the depth associations contributed little in separating species clusters. Depth was represented here indirectly via the flow type axis with pool habitats being typically deeper than other habitats (riffles and runs) within individual stream reaches (Jowett 1993). The combinations of the categories in the substrate (3), cover (3), and flow type (2) result in 18 habitat types. By fish group and life stage, the association ratings were summed for each habitat category (Table 8). Then, the sums were divided by the habitat class maximum to give partial habitat suitabilities by category within classes. Finally, the combinations of partial suitabilities for categories from all three classes were cross-multiplied to produce suitabilities by habitat type (Table 8). For example, in the 1+ life stage of the Cold×A2 group the combination of flow-pool (P=1.000) times substrate-large (L=0.533) times cover-no (N=0.828) give the suitability of the PLN habitat type (0.441). These steps repeated for all combinations resulted in a habitat suitability matrix for 18 habitat types by eight fish groups and two life stages.

Pool suitabilities were mostly higher than the Other flow type and 1+ suitabilities were generally higher than those for spawning (Figure 2). Across SP suitabilities, medium substrate (sand and gravel) with no cover had the highest values in both flow classes. For mean 1+ suitabilities, medium substrate with no cover had the highest Pool value and medium substrate with plant cover had the highest in the Other flow type. Among the species and life stage groups, the minimum suitability was zero in all but two of the habitat combinations (pool/large and medium substrates/no cover; PLN and PMN) and the maximum suitability was one that occurred in four habitat types (all covers for pool with medium substrates: PMP, PMW, and PMN; and flow-other with medium substrate and no cover, OMN). Compared to the 1+ Cold×A2 group, the 1+ Warm×B group (dominated by centrarchid species) had higher suitabilities for plant cover (vegetation, algae) compared to wood/substrate and no cover, pool suitabilities were higher than flow-other, and medium and small substrate were suitabilities higher than large substrate (Figure 2). Thus, aside from their different thermal preferences, the salmonids and centrarchids have well-delineated preferences between physical habitat features.

The overall patterns of habitat association were consistent across thermal and life stage groupings (Figure 3). 1+ patterns were broader than SP ones in each group, indicating a greater diversity of suitable habitats for adult fishes. Among 1+, the cool reproductive groups had the

broadest habitat suitabilities with much overlap while the cold and warm groups showed less overlap among spawning guilds. In comparison, the SP patterns were restricted with a strong affinity for medium substrates (M; gravel and sand) in both flow classes and for wood/substrate/overhead (W) cover in pools. Cool-water groups habitat suitability patterns in both stages were broader than those of cold and warm water ones.

STREAM HABITAT ASSESSMENT MODEL

To use the habitat suitability matrix to assess the potential impact of development activities on stream habitat at a particular site, a set of fish group and life stage weighting values is required for calculations. Not all suitabilities will be given equal weight in a particular site assessment because of factors such as the relative supply of habitat types, the species assemblage presenting that river system, and the prevailing thermal regime. The stream characteristics, the species assemblage present in the local watershed, the life history characteristics of the species present, and the fish habitat management objectives (e.g., fisheries, biodiversity, or species-at-risk status) all influence the selection of weights.

Three factors contribute to weight-setting: life stages, thermal preferences, and fish community objectives (Table 9). First, the life stages must be weighted. The traditional tendency among fishery biologists has been to give spawning habitat the greatest weight. Simulation models (Minns 2003) indicate that the habitat limitations have the greatest impact on fry (0+) and juveniles, and the least on spawning. The presence of habitats suitable for all life stages at a proposed development site is unlikely and, hence, not all life stage habitats need to be considered in every case. Unfortunately, fry habitat association is poorly known for most freshwater fishes but is expected to be similar to spawning habitat associations, especially in guarder (B) and brood hider (A2) reproductive guilds wherein fry tend to stay where their eggs were placed and incubated. Therefore, equal weights are recommended for the spawning and 1+ life-stage suitabilities until further evidence emerges (Table 8). Second, the thermal guild weights should be determined by the temperature regime of the stream being assessed. Stoneman and Jones (1996) provided a sound basis for classifying southern Ontario streams using maximum summer stream temperatures which reflect the degree of contribution of groundwater to base-flow in the summer. The proposed framework (Table 9) recognizes that aside from the three main stream thermal types, transitional states from cold to cool and from cool to warm occur (Stoneman and Jones 1996). Thus, prior to applying the habitat assessment model, it will be necessary to determine the thermal regime at the assessment site on the stream. The temperature regime encountered at a stream site leads to expectations of which fish groups are likely to occur and thrive. Thirdly, the fish community weightings usually consider fisheries potential and species richness along with fishery management objectives. In this study, a generic recommendation is made (Table 9) based on the complete set of 128 fish species found in Ontario streams. The fisheries potential of the fish groups was estimated using the reported occurrences of exploitation of the species (Coker et al. 2001). Among cold-water species, the A2 reproductive guild (mainly salmonids) had more exploited species than A1 (mainly lake species) and both had more than group B (sculpins and sticklebacks). Among cool-water species more A1s (mainly percids) are exploited than Bs (mainly panfish) and both more than group A2. Among warm-water species, more Bs (mainly centrarchids) are exploited than in group A. The species diversity considerations were based on the numbers of species in the fish groups (Table 6); groups with larger number of species were given higher weights. When the habitat assessment model is applied in a specific area, the local species assemblage should be determined preferably on a watershed scale (i.e., tertiary watershed) using prior inventory records rather than a list of species found at the target site that is often obtained using limited sampling effort. Fishes can migrate considerably within stream networks, unless barriers

intervene, and determining a complete species list in an area requires extensive spatial and temporal data. From an ecosystem perspective, the suitability of a stream site for all the potential species in an area should be assessed rather than a limited subset as all species can contribute to the site's energy flow and production dynamics.

Once a stream thermal regime has been selected, the cross-products of assigned life-stage, thermal, and reproductive weights generate an overall weighting for use in combining the 16 fish group suitabilities for any habitat combination into a single value. Using the recommended rules for weights (Table 9) in a cold water stream, the 1+ and SP Cold×A2 weights are both 0.32 (= 0.5 x 0.8 x 0.8) while the 1+ and SP Warm×B weights are both 0.0 (= 0.5 x 0.0 x 0.7). As with each constituent set of weights, the sum of the combined weights is 1.0. In this example, the ColdHA2 weights account for 64% of the total as might be expected for a cold water stream with a valued salmonid fishery. Thus, weighting allows the emphasis in a habitat assessment to be applied to the fish groups most appropriate to the stream thermal regime as well as to the local fishery and species diversity priorities.

To illustrate the application of this stream habitat assessment model, consider a 1000 m^2 reach of a cold water stream (maximum summer stream temperature <17°C). A development proposal will change the amounts of different habitat types within the reach with the greatest change occurring in these proportions by flow type from 50% Pool and 50% Other to 25% Pool and 75% Other (Table 10). Such a change might arise from some sort of channelization or straightening of the reach. Further, the proportions of: (1) large substrate (L) will be increased and small substrate (S) are decreased in flow type Other (O) patches, and (2) wood/substrate (W) cover is increased and no cover (N) is decreased in flow type Other (O) with medium (M) substrate patches. The habitat changes between the pre- and post-development scenarios cause the weighted suitable area (WSA) to decrease from 375.8 to 344.9 m^2, representing a net loss of 30.9 m^2. To further assess the impact of develop scenarios, the individual WSA values for different fish groups and life stages can be inspected. Decreases in WSA for the PMN and PSN habitat types were not offset by increases in the OMN habitat type, given that the dominant adult and juvenile contributor to the composite suitability, 1+ ColdHA2, has higher suitabilities for Pool habitats. Given the equal weights for all life stages, the high suitability of OMN for SP ColdHA2 and very low suitabilities for most other flow type Other habitats did not offset the 1+ losses. Given the projected net loss, the habitat manager can ask for modifications to the development activity to achieve a net gain.

In this example, the development activity is assumed to leave the stream discharge and thermal regimes unaltered. If development alters these stream features, the stream habitat assessment model can be augmented via consideration of "condition factors" (cf Minns et al. 2001) whereby the impact of non-physical changes in stream habitat can be incorporated into the assessment. For example, if the development outlined above also shifted the stream thermal regime from cold to cool but the fishery and diversity objectives remain unchanged, the condition factor for the post-scenario might be changed from a default value of 1 to, say, 0.5 to reflect the decreased value of the cool habitat for cold water fishes. The post-scenario WSA is multiplied by 0.5, making the net loss much larger compared to the unadjusted pre-scenario (203.3 vs 30.9 m^2). Condition factors can be used to represent discharge, thermal, water quality, and other changes between pre- and post-scenario pairs whether conditions improve or degrade while the habitat types, the fish groups and life stages, and the assessment weights remain the same. Condition factors must be applied with care and with supporting rationales to avoid them being used arbitrarily to override the habitat suitabilities (Minns et al. 2001).

DISCUSSION

The analyses and modelling of habitat associations of Ontario stream fishes showed, that despite limited observation for many species, fish groups based on life history characteristics can provide an acceptable representation of variations in habitat association. The low correlations among habitat categories (within and between life stages) indicate the habitat variables each provide information useful for the suitability matrix modelling (i.e., redundancy is low). A cluster analysis produced equal numbers of significant species and habitat variable groupings. However, the species groupings mixed species with differing thermal preferences and taxonomic positions. The clusters of habitat variables mostly kept adult and juvenile associations apart from spawning ones and depth associations contributed little to the identification of fish groups. The separation of adult and juvenile preferences from spawning ones may be attributable in part to the relative sparseness of the two data sets. Therefore, the final species groups used for the habitat suitability matrix model could not be based solely on the groups obtained by cluster analysis as fishery and habitat biologists have *a priori* expectations about assemblages/ guilds/communities of fish species. The final groups were based on two factors: temperature preference and spawning guilds; the higher levels of Balon's (1990) hierarchical scheme. The analyses of a range of temperature metrics showed consistent linear relationships among various preferred and upper limiting temperatures and that the estimated final temperature preferenda divided easily into three groupings (cold, cool, and warm) in line with expectations among freshwater fish biologists. The combination of temperature preference and reproductive guilds showed considerable agreement with the groups obtained by clustering species. The habitat suitability matrix was derived using a similar approach to that used by Minns et al. (2001) for fishes in lake habitats. The consistency of the fish groupings, the suitability matrix, and the temperature preference results with other studies are considered further below.

Two complementary approaches to the formation of fish habitat classifications have developed; one centred on geomorphologic and hydraulic characteristics of the habitats (Welcomme et al. 2006, Goldstein and Meador 2004) and the other on the biological characteristics of the species (Aadland 1993, Detenbeck et al. 1992). The approaches often overlap as they converge in species and life-stage associations for various habitat features (Vadas and Orth 2000, Lamouroux and Souchon 2002). The formation of guilds or groups is a common feature of classification schemes. The results and assessment model presented in this study exemplify the complementary features; the biological criteria (thermal preference and spawning guild) produce groups consistent with the clustering of associations for habitat categories. The habitat combinations reflect geomorphologic (via substrates and cover types) and hydraulic (pool versus non-pool) features.

The clusters of species habitat associations presented here are consistent with other studies such as Aadland (1993) and Lamouroux and Souchon (2002). Working in Minnesota streams, Aadland (1993) derived a simple scheme of six habitat types; three pool types based on depth, slow and fast riffles, and raceways. His pool types were characterized by small-size or mixed-size substrates with cover types mainly associated with wood or substrates. The non-pool types mainly had large-sized substrates (e.g., cobble, rubble) with plants and substrates providing most cover in riffles and substrates like boulders in raceways. He identified habitat specific fish assemblages without regards to thermal preferences, although most of his species preferred warm or cool waters. The schema presented here is consistent with Aadland's observations although the details differ. This schema is based primarily on grouping spawning and habitat preferences whilst Aadland's is based primarily of habitat features. Goldstein and Meador (2004) presented a continental analysis emphasizing the role of stream or river size in

structuring fish communities. Their results parallel the groupings proposed by Welcomme et al. (2006). Given the origin of many of the species habitat association observations (Portt et al. 1999), the current schema targets small streams. Lamouroux and Souchon (2002) showed how the habitat preference patterns of their guilds were strongly related to percent pools (indicative of geomorphology) and median flow (indicative of hydraulics). Detenbeck et al. (1992) showed how the rate of recovery of stream fish communities after disturbance is related to both thermal preferences and reproductive guilds.

Temperature is a dominant factor determining the productivity and persistence of fish populations (Magnuson et al. 1979). The significance of the linear regression models linking final temperature preferenda to other temperature metrics was consistent with the geometric framework of Beitinger and Bennett (2000) that predicts consistent relationships among lower and upper temperature limits and preferred temperatures in freshwater fishes. The results were similar to those obtained by Jobling (1981) and Richardson et al. (1994) showing linear relationships among optimum growth, final preferred, and lethal temperatures. The presence of well-defined separations of cold, cool, and warm water fishes is consistent with received fisheries knowledge. The temperature cut-offs separating the thermal guilds were a few degrees Celsius above the maximum stream temperature thresholds in the summer identified by Stoneman and Jones (1996) for classifying cold, cool, and warm water streams in southern Ontario, indicating that the thermal regime of S. Ontario streams can be readily classified. This would be expected given that few species FTP values lie close to the cut-offs. The geological and physiographic features in Southern Ontario strongly influence stream temperatures (Piggott et al. 2005), producing thermal conditions at the site-level which are usually well-delineated (Stoneman and Jones 1996). Most Ontario streams lie clearly within one of the three ranges shaped by the levels of cold groundwater contribution to flow are strongly related to the thermal diversity of stream fishes (Chu et al. 2008). These analyses confirmed the need to consider temperature preference in forming fish species groups for the habitat suitability matrix.

The analyses and modelling presented here were based on literature-based reviews of the habitat associations and other ecological attributes of stream-dwelling fishes found in the Great Lakes basin of Ontario. These data are indicative of the limited knowledge base upon which fish habitat managers must make decisions every day. However, the habitat suitability matrix patterns derived via these analyses are consistent for salmonids as compared with more detailed evaluations reported in S. Ontario streams (Stoneman and Jones 2000, Stanfield et al. 2006). The higher suitability values obtained for 1+ Cold×A2 (salmonids and lampreys) were comparable to the weights obtained by Stoneman and Jones (2000) in discriminant analyses to predict trout biomass in southern Ontario streams: pools, medium and small substrates with wood/substrate/overhead cover (Figure 2). The numbers of habitat combinations and fish guilds considered in the suitability matrix were constrained by the data availability. Expansion of the matrix to consider more finely delineated groups, or even species, and life stages would likely require a greater diversity of habitat categories, which in turn would require more detailed habitat inventories. Species level delineation of habitat requirements should be possible because each species is presumed to occupy a separate niche. However, efforts to completely detail habitat requirements for all species and life stages must be balanced against the need to manage whole ecosystems and species assemblages. In this study, even a simple approach leads to an 18 by 16 matrix. The application of weighting to reflect stream habitat and fish community characteristics at any particular site will result in only portions of the whole assessment model being used in each instance.

The stream habitat assessment model was developed using the approach previously used with success for lake habitats (Minns et al. 2001, Minns and Nairn 1999). Habitat equivalency is the basis for this, and many other habitat assessment schemes (Minns 1997, Dunford et al. 2004, Lamoroux and Souchon 2002). The combination of a simple habitat suitability matrix (fish groups by habitat types) and a group-weighting scheme will allow applications to be tuned to local stream thermal conditions and management objectives and provide a transparent and consistent basis for assessment of proposed developments.

The stream habitat assessment model presented here provides a simple, *a priori,* or first order, means for assessing net change of productive capacity of fish habitat in Ontario streams. Given the large numbers of development sites being examined, often by class rather than individually assessed, the collection of detailed site-specific fish community and habitat data is precluded in many instances. Yet, it remains important to make the best use of available scientific knowledge to guide decision making. Further, since regulatory approval of proposed habitat modifications requires some forecasting or prediction of future conditions, some form of systematic, quantitative analysis will be necessary. No attempt was been made to validate the suitability matrix model as it represents a summation of literature-derived evidence of habitat association. However, validation analyses with the equivalent lake habitat assessment model (Minns et al. 2001) in the lower Great Lakes showed good agreement between suitability values and a range of standardized electro-fishing catch metrics for cool and warm water fishes in shallow nearshore habitats. If extensive standardized data were available for Ontario streams spanning all stream conditions and fish community types, a validation exercise would be appropriate but, equally, such a database would enable the derivation of an empirical data-driven assessment and overcome the need for a simple, *a priori,* model. Growing use of the Ontario Stream Assessment Protocol (OSAP; Stanfield 2005) is facilitating the accumulation of that kind of habitat data. Initial analyses for salmonid streams in Southern Ontario (Stanfield et al. 2006) indicate that improved assessment models can be developed (e.g., showing the importance of including imperviousness on a landscape scale alongside the local scale habitat variables such as flow type, substrate, and cover). Then effects at various scales can be taken into account when assessing proposed habitat alterations.

Simple literature-based habitat assessment models provide a starting point for progressively improving the scientific basis for conserving and protecting fish habitat (Rosenfeld 2003). In many projects affecting stream habitat in Canada and the United States, little effort is applied to estimating potential impacts or assessing them afterwards (Quigley and Harper 2006a, b, Palmer et. al 2007). In Newfoundland, a simple consensus-based four-class assessment model has been used for salmonids in streams for some years (Scruton et al. 2005). The classes in that model are defined using flow, depth, and substrate characteristics. Stream habitat survey methods have advanced in recent years with improved standardization for delineation of flow characteristics (Jowett 1993) and determining the distributions of substrate types/sizes and cover types (Stoneman and Jones 2000, Jowett and Richardson 1995). These improvements facilitate the application of quantitative assessment of proposed habitat changes. Doubtless in future more elaborate multi-scale models will be developed as more data are collected and as understanding accumulates. In the meantime, simple models like that presented here provide a sound foundation for science-basis assessment of proposed site-specific changes to stream fish habitats in Ontario.

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Table 1. Condensed habitat association classes and categories for 128 stream fish species at two life stages (adult and juvenile - 1+ and spawning - SP) were rated in terms of x = 0, 1 (1<= x <2), 2 (2<= x <3), 3 (=>3) where x = rating index, the inferred degree of association.

Habitat Class	1+				SP			
Category	0	1	2	3	0	1	2	3
Depth, cm*								
0-60	43	2	2	81	68	0	3	57
61-100	43	2	2	81	86	0	4	38
101+	104	0	5	19	86	0	4	38
Substrate								
Large	55	38	22	13	90	30	1	7
Medium	27	2	21	78	42	0	0	86
Small	43	9	38	38	111	0	2	15
Cover								
Plant	68	1	9	50	94	1	1	32
Wood/Sub	79	34	2	13	89	24	2	13
None	28	60	1	39	23	37	0	68
Flow								
Pool	18	10	5	95	55	0	2	71
Other	52	59	7	10	67	56	0	5

* In depth, the ratings in 0-60 and 61-100 were the same for 1+ and those for 61-100 and 101+ for spawning.

Table 2. Pearson correlations (r) among habitat association ratings for 128 Ontario stream fish species, within adult and juvenile associations (1+ to 1+), between adult-juvenile and spawning associations (SP in rows to 1+ in columns), and within spawning associations (SP to SP). Values of r greater than 0.3 are significant at a Bonferroni-adjusted P=0.05 and are highlighted in **bold**.

		Depth			Substrate			Cover			Flow	
		0-60	61-100	101+	Large	Medium	Small	Plant	Wood/Sub	None	Pool	Other
1+ to 1+												
Depth	0-60											
	61-100	**1.000**										
	101+	0.164	0.164									
Substrate	Large	0.277	0.277	0.238								
	Medium	0.204	0.204	0.009	**0.503**							
	Small	**0.315**	**0.315**	-0.133	-0.036	0.269						
Cover	Plant	0.213	0.213	-0.111	-0.050	0.045	0.165					
	Wood/Sub	0.049	0.049	-0.003	0.231	0.193	-0.024	-0.089				
	None	-0.187	-0.187	0.114	-0.103	-0.200	-0.108	**-0.577**	**-0.674**			
Flow	Pool	0.128	0.128	-0.138	-0.054	**0.320**	0.170	0.197	-0.069	-0.096		
	Other	-0.012	-0.012	0.021	**0.355**	0.280	-0.075	-0.092	0.153	-0.021	0.015	
SP to 1+												
Depth	0-60	0.032	0.032	0.188	0.168	0.064	-0.018	0.012	0.084	-0.063	-0.042	-0.119
	61-100	-0.038	-0.038	0.243	0.194	0.014	0.080	-0.159	0.044	0.142	-0.014	-0.045
	101+	-0.038	-0.038	0.243	0.194	0.014	0.080	-0.159	0.044	0.142	-0.014	-0.045
Substrate	Large	-0.119	-0.119	0.163	0.201	-0.053	-0.261	-0.200	-0.033	0.178	-0.135	0.029
	Medium	0.091	0.091	-0.061	0.248	0.142	-0.104	-0.227	0.260	-0.033	-0.134	0.044
	Small	0.139	0.139	0.074	-0.099	0.030	0.218	0.090	-0.031	-0.004	0.037	-0.230
Cover	Plant	0.215	0.215	0.110	-0.107	-0.160	0.294	**0.357**	-0.246	-0.092	0.136	-0.234
	Wood/Sub	0.054	0.054	0.026	0.095	0.093	0.109	0.028	0.189	-0.212	-0.002	0.157
	None	-0.138	-0.138	-0.035	0.039	0.019	-0.261	-0.283	0.002	0.268	-0.121	0.036
Flow	Pool	0.187	0.187	-0.123	-0.015	0.043	0.269	**0.359**	-0.184	-0.133	0.266	-0.064
	Other	-0.216	-0.216	0.050	0.191	0.109	-0.239	-0.266	0.251	0.009	-0.110	**0.321**
SP to SP												
Depth	0-60											
	61-100	**0.309**										
	101+	**0.309**	**1.000**									
Substrate	Large	-0.002	0.196	0.196								
	Medium	0.158	0.146	0.146	0.250							
	Small	0.232	0.094	0.094	-0.126	0.069						
Cover	Plant	0.126	0.020	0.020	-0.204	**-0.365**	0.043					
	Wood/Sub	0.127	0.012	0.012	0.003	-0.034	0.105	0.083				
	None	-0.181	0.066	0.066	0.101	0.244	-0.111	**-0.620**	**-0.779**			
Flow	Pool	0.107	0.093	0.093	-0.203	-0.099	0.263	**0.416**	0.156	**-0.401**		
	Other	0.001	-0.080	-0.080	0.161	**0.361**	**-0.305**	**-0.394**	-0.063	0.267	-0.263	

Table 3. Cross-tabulation and summary of species (rows) and habitat association (columns) clusters arising from the Orloci information metric analysis as a percentage of entries within the intersecting cells of row and column clusters with ones (zero values are shaded grey, values ≥80.0 are shown in **bold**). The number of species or habitat categories and rating levels) included in each cluster is shown along with the habitat features present in the habitat cluster.

		Habitat association clusters											
		H1	H12	H3	H4	H5	H6	H7	H8	H9	H10	H11	#Spp
Species clusters	S1	9.1	47.5	77.3	60.6		33.3	4.5	36.4		9.1	55.6	11
	S2	**80.0**	70.0	58.8	58.3	**93.3**	35.0	3.3	40.0			40.0	10
	S3	**100.0**	52.2	**91.3**	3.3	33.3	15.0	15.0			77.5	21.1	10
	S4	**81.3**	56.9	63.3	32.3	50.0	18.8		31.3		50.0	60.4	16
	S5		16.2	43.3	5.1		11.5	3.8	46.2	59.0	**92.3**	56.4	13
	S6	51.5	62.6	55.7	6.1		3.0	28.8	54.5	9.1	**90.9**	45.5	11
	S7	66.7	73.8	70.5	19.0	40.5	27.4	14.3	42.9	**100.0**	67.9	55.6	14
	S8	59.5	30.2	**87.5**	2.4	**92.9**	**96.4**	2.4	28.6	4.8	7.1	1.6	14
	S9	**100.0**	47.8	**81.3**	18.3	**90.0**	**88.3**	28.3	**80.0**	6.7	10.0	31.1	10
	S10	**92.9**	42.9	78.6	40.5	50.0	78.6	45.2	**92.9**	**97.6**	25.0	22.2	14
	S11	**93.3**	68.9	40.0	66.7	20.0	40.0	36.7	60.0	60.0		62.2	5
	#Habitats	6	9	8	6	3	6	6	3	6	4	9	
	Stage	1+	1+	1+	1+,SP	1+	SP	1+,SP	SP	SP	1+,SP	SP	
	Depth	<100						>100(1+)	<60	>60			
	Substrate		L,M	S				S (SP)				L,M	
	Cover			No(L)	Wd/Sub	Plant	Plant				No(M,H)		
	Flow		Other	Pool			Pool					Other	

* Stage: 1+-Adult and Juvenile, SP- Spawning; Substrate: L-Large, M-Medium, S- Small; Cover: No-None, Wd/Sub-Wood/Substrate, (L-Low, M-Medium, H-High).

Table 4. Fish species belonging to the eleven species clusters obtained using the Orloci information metric and Q-test clustering of adult+juvenile and spawning habitat association ratings.

Cluster	Species membership
S1	American Brook Lamprey; Sea Lamprey; Silver Lamprey; Northern Brook Lamprey; Brindled Madtom; Northern Madtom; Channel Catfish; Channel Darter; Cutlips Minnow; Lake Chubsucker; Tessellated Darter
S2	Black Crappie; Central Stoneroller; Johnny Darter; Yellow Bullhead; Ninespine Stickleback; Spotfin Shiner; Slimy Sculpin; Fantail Darter; Tadpole Madtom; Mottled Sculpin
S3	American Eel; Blackchin Shiner; Pugnose Minnow; Blacknose Shiner; Sand Shiner; Ghost Shiner; Brassy Minnow; Quillback; Rosyface Shiner; Striped Shiner
S4	Atlantic Salmon; Coho Salmon; Eastern Sand Darter; Hornyhead Chub; Longnose Dace; Eastern Blacknose Dace; White Sucker; Redside Dace; Creek Chub; Logperch; Common Shiner; Trout-perch; Redfin Shiner; Tubenose Goby; Spottail Shiner; Threespine Stickleback
S5	American Shad; Pygmy Whitefish; Lake Chub; Longnose Sucker; Spoonhead Sculpin; Arctic Charr; Cisco (lake herring); Lake Whitefish; Chinook Salmon; Pink Salmon; River Redhorse; Silver Redhorse; Sauger
S6	Black Redhorse; Golden Redhorse; Fallfish; Northern Hognose Sucker; Rainbow Smelt; White Perch; Freshwater Drum; Mooneye; Greater Redhorse; Shorthead Redhorse; Silver Shiner
S7	Blackside Darter; Bluegill; Burbot; Pearl Dace; Brown Trout; Rainbow Trout; Spotted Sucker; Walleye; Emerald Shiner; White Bass; River Chub; Lake Sturgeon; Rainbow Darter; River Darter
S8	Banded Killifish; Brook Stickleback; Mimic Shiner; Blackstripe Topminnow; Central Mudminnow; Grass Pickerel; Longnose Gar; Northern Redbelly Dace; Bigmouth Buffalo; Bridle Shiner; Pugnose Shiner; Bowfin; Goldfish; Rudd
S9	Brook Silverside; Gizzard Shad; Eastern Silvery Minnow; Longear Sunfish; Orangespotted Sunfish; Pumpkinseed; Golden Shiner; Green Sunfish; Iowa Darter; Least Darter
S10	Black Bullhead; Yellow Perch; Muskellunge; Northern Pike; Ruffe; Warmouth; Brown Bullhead; White Crappie; Largemouth Bass; Rock Bass; Bluntnose Minnow; Fathead Minnow; Common Carp; Finescale Dace
S11	Brook Trout; Smallmouth Bass; Round Goby; Greenside Darter; Stonecat

Table 5. Linear regression models to predict the final temperature preferendum (FTP) in freshwater fishes using alternate temperature reference end-points as the input variable and their hierarchies order of use to estimate missing FTP values.

Input*	Intercept	Slope	Correlation	N	Order of use to estimate FTP
OPT	2.647	0.887	0.954	29	1
IULT/CMT	-12.366	1.108	0.831	32	2
MTT	-10.845	1.187	0.781	22	3
PT	5.726	0.787	0.629	27	4

* OPT – Optimum preferred temperature; IULT – Incipient upper lethal temperature; CMT – Critical maximum temperature; MTT – Maximum temperature tolerance; and PT – Preferred temperature.

Table 6. Cross-tabulation of number of species in clusters (Table 4) based on thermal preference, spawning or reproductive guild, a combination of thermal preference and spawning guilds, turbidity tolerance, and a summary of species maximum body length by species cluster.

Species cluster	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
Number of species	11	10	10	16	13	11	14	14	10	14	5
Thermal guild											
Cold	2	3	0	4	10	0	5	0	0	0	1
Cool	4	3	4	9	3	5	5	6	5	6	3
Warm	5	4	6	3	0	6	4	8	5	8	1
Reproductive guild											
A1: Non-guarders: Open substratum	1	1	9	9	9	10	7	12	6	6	1
A2: Non-guarders: Brood hiders	5	1	0	4	3	1	6	0	0	0	1
B1: Guarders: Substratum choosers	0	0	0	0	0	0	0	0	0	1	1
B2: Guarders: Nest spawners	5	8	1	3	1	0	1	2	4	7	2
Fish Groups											
Cold×A1	0	0	0	1	6	0	3	0	0	0	0
Cold×A2	2	0	0	2	3	0	2	0	0	0	1
Cold×B	0	3	0	1	1	0	0	0	0	0	0
Cool×A1	0	0	3	6	3	4	1	5	5	4	1
Cool×A2	3	0	0	2	0	1	4	0	0	0	0
Cool×B	1	3	1	1	0	0	0	1	0	2	2
Warm×A	1	2	6	2	0	6	3	7	1	2	0
Warm×B	4	2	0	1	0	0	1	1	4	6	1
Turbidity tolerance											
Unknown	4	7	2	6	9	3	6	5	0	2	1
Yes	1	3	2	6	2	1	1	4	4	8	1
No	6	0	6	4	2	7	7	5	6	4	3
Maximum body length (log_{10}, mm)											
Mean	2.33	2.12	2.18	2.23	2.68	2.69	2.50	2.28	2.12	2.54	2.42
Standard deviation	0.38	0.32	0.48	0.40	0.26	0.23	0.46	0.49	0.31	0.39	0.23
Coefficient of variation %	16.36	15.31	21.79	17.87	9.63	8.63	18.34	21.47	14.45	15.17	9.40
Geometric mean, mm	214	132	151	170	479	490	316	191	132	347	263

Table 7. List of Ontario stream fish groups formed using a combination of thermal preference and spawning guilds (character, species membership and species number).

Group	#	Group defining characteristics and species lists
COLD×A1	10	*Primarily lake fish*: American Shad; Burbot; Cisco (Lake Herring); Lake Chub; Lake Sturgeon; Lake Whitefish; Longnose Sucker; Pearl Dace; Pygmy Whitefish; Trout-perch
COLD×A2	10	*Stream salmonids and lampreys*:American Brook Lamprey; Arctic Charr; Atlantic Salmon; Brook Trout; Brown Trout; Chinook Salmon; Coho Salmon; Pink Salmon; Rainbow Trout; Sea Lamprey
COLD×B	5	*Sculpins and sticklebacks:* Mottled Sculpin; Ninespine Stickleback; Slimy Sculpin; Spoonhead Sculpin; Threespine Stickleback
COOL×A1	32	*Percids, redhorses, dace, darters, and others:* American Eel; Banded Killifish; Black Redhorse; Eastern Blacknose Dace; Brassy Minnow; Bridle Shiner; Brook Silverside; Eastern Sand Darter; Finescale Dace; Gizzard Shad; Golden Redhorse; Golden Shiner; Greater Redhorse; Greenside Darter; Iowa Darter; Least Darter; Longnose Dace; Northern Pike; Northern Redbelly Dace; Pugnose Shiner; Quillback; Rainbow Smelt; Redfin Shiner; Redside Dace; River Redhorse; Rudd; Ruffe; Sauger; Silver Redhorse; Walleye; White Sucker; Yellow Perch
COOL×A2	10	*Non-quarder darters, chubs, and lampreys:* Blackside Darter; Channel Darter; Creek Chub; Fallfish; Hornyhead Chub; Northern Brook Lamprey; Rainbow Darter; River Chub; River Darter; Silver Lamprey
COOL×B	11	*Guarder darters, pomoxids, and others:* Round Goby; White Crappie; Black Crappie; Brook Stickleback; Common Shiner; Fantail Darter; Johnny Darter; Rock Bass; Stonecat; Striped Shiner; Tessellated Darter
WARM×A	30	*Shiners, moronids, gar, suckers, and others*:Bigmouth Buffalo; Blackchin Shiner; Blacknose Shiner; Blackstripe Topminnow; Central Mudminnow; Common Carp; Eastern Silvery Minnow; Emerald Shiner; Freshwater Drum; Ghost Shiner; Goldfish; Grass Pickerel; Lake Chubsucker; Logperch; Longnose Gar; Mimic Shiner; Mooneye; Muskellunge; Northern Hognose Sucker; Pugnose Minnow; Rosyface Shiner; Sand Shiner; Shorthead Redhorse; Silver Shiner; Spotfin Shiner; Spottail Shiner; Spotted Sucker; White Bass; White Perch
WARM×B	20	*Centrarchids, minnows, bullheads*:Central Stoneroller; Black Bullhead; Bluegill; Bluntnose Minnow; Bowfin; Brindled Madtom; Brown Bullhead; Channel Catfish; Cutlips Minnow; Fathead Minnow; Green Sunfish; Largemouth Bass; Longear Sunfish; Northern Madtom; Orangespotted Sunfish; Pumpkinseed; Smallmouth Bass; Tadpole Madtom; Tubenose Goby; Warmouth; Yellow Bullhead

Table 8. Demonstration of the steps required to calculate habitat suitability matrix values for two fish groups, 1+ Cold×A2 and 1+ Warm×B**,. First, A) the species' selection ratings are summed by habitat category within each fish group/life stage combination. Then B) the partial suitabilities are computed by dividing by the maximum sum within each habitat class. Finally, C) combinations of partial suitabilities from all three habitat classes are cross-multiplied to estimate the habitat suitabilities.

Habitat			A) Sum of selection ratings		B) Partial suitabilities		C) Habitat suitability		
Class	Category	Code*	1+ Cold×A2	1+ Warm×B	1+ Cold×A2	1+ Warm×B	Type*	1+ Cold×A2	1+ Warm×B
Flow	Pool	P	18.0	46.0	1.000	1.000	PLP	0.110	0.480
	Other	O	5.0	23.0	0.278	0.500	PLW	0.533	0.324
Substrate	Large	L	8.0	23.5	0.533	0.480	PLN	0.441	0.212
	Medium	M	15.0	49.0	1.000	1.000	PMP	0.207	1.000
	Small	S	11.0	46.0	0.733	0.939	PMW	1.000	0.676
Cover	Plant/Algae	P	3.0	34.0	0.207	1.000	PMN	0.828	0.441
	Wood/Sub	W	14.5	23.0	1.000	0.676	PSP	0.152	0.939
	No	N	12.0	15.0	0.828	0.441	PSW	0.733	0.635
							PSN	0.607	0.414
							OLP	0.031	0.240
							OLW	0.148	0.162
							OLN	0.123	0.106
							OMP	0.057	0.500
							OMW	0.278	0.338
							OMN	0.230	0.221
							OSP	0.042	0.469
							OSW	0.204	0.318
							OSN	0.169	0.207

*The first letter in the type code refers to flow category, the second to substrate category, and the third to cover category.
** 1+ refers to life stage – adult and juvenile, Warm and Cold refer to thermal preference, and A2 and B refer to spawning guilds.

Table 9. Recommended weights for life stages, stream thermal regimes and fish thermal guilds, and fish community objectives (fishery potential-F and species richness or biodiversity-S), using thermal and reproductive guilds, when pooling fish group suitabilities in an application of the stream habitat assessment model.

Criterion		Category				Rationale*
Life-stage		1+	Spawning			Area: Fry > Juvenile > Adult > Spawning
		0.5	0.5			(Juvenile + Adult) = (Spawning + Fry)
Thermal Guild	Max. T (°C)	Cold	Cool	Warm		Summer maximum stream temperature (T)
	< 17	0.8	0.2	0.0		Cold water stream
	~ 17	0.5	0.5	0.0		Transitional cold-cool water stream
	> 17 & < 23	0.1	0.8	0.1		Cool water stream
	~ 23	0.0	0.5	0.5		Transitional cool-warm water stream
	> 23	0.0	0.2	0.8		Warm water stream
Fish	Reproductive	A1	A2	A	B	Fishery potential (F) and species richness (S)
Community	Guild					
Thermal	Cold	0.3	0.6	na	0.1	F: A2 > A1 > B; S: A1 = A2 > B
Guild	Cool	0.5	0.3	na	0.2	F: A1 > B > A2; S: A1> A2 = B
	Warm	na	na	0.5	0.5	F: B > A; S: A > B

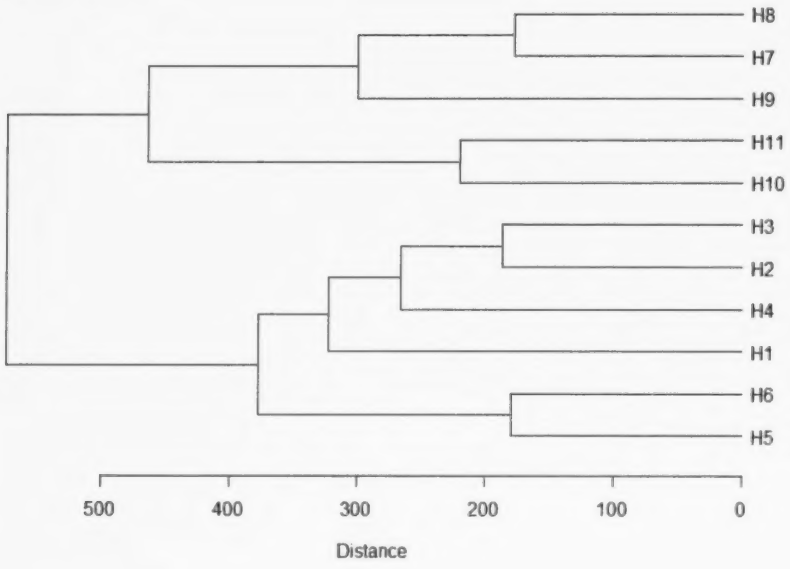
* The greater than (>) and equal (=) signs are used in the rationale section to indicate the likely relative importance of spawning groups of species within thermal guilds with respect to each criterion.
na – not applicable.

Table 10. A demonstration calculation of weighted suitable area (WSA) for pre- and post-development scenarios on a 1000 m^2 reach of a cold water stream. The composite suitability is the weighted mean of suitabilities for all fish groups and life stages obtained using the weights recommended for a cold water stream in Table 9. The habitats are apportioned by habitat class, first flow type, then substrate within flow type, and finally by cover within flow type and substrate.

Habitat Type	Flow Type	Substrate	Cover	Composite Suitability	Pre-scenario					Post-scenario				
					% Flow	% Subst.	% Cover	Area m^2	WSA m^2	% Flow	% Subst.	% Cover	Area m^2	WSA m^2
PLP	Pool	Large	Plant	0.135	0.500	0.100	0.100	5.00	0.68	0.250	0.200	0.100	5.00	0.68
PLW			Wd/Su	0.269			0.500	25.00	6.73			0.500	25.00	6.73
PLN			None	0.327			0.400	20.00	6.53			0.400	20.00	6.53
PMP		Medium	Plant	0.242		0.500	0.200	50.00	12.10		0.600	0.200	30.00	7.26
PMW			Wd/Su	0.497			0.200	50.00	24.84			0.200	30.00	14.90
PMN			None	0.710			0.600	150.00	106.51			0.600	90.00	63.90
PSP		Small	Plant	0.135		0.400	0.200	40.00	5.41		0.200	0.200	10.00	1.35
PSW			Wd/Su	0.299			0.000	0.00	0.00			0.000	0.00	0.00
PSN			None	0.321			0.800	160.00	51.43			0.800	40.00	12.86
OLP	Other	Large	Plant	0.066	0.500	0.200	0.000	0.00	0.00	0.750	0.300	0.000	0.00	0.00
OLW			Wd/Su	0.094			0.400	40.00	3.76			0.400	90.00	8.46
OLN			None	0.161			0.600	60.00	9.64			0.600	135.00	21.70
OMP		Medium	Plant	0.109		0.600	0.100	30.00	3.26		0.600	0.100	45.00	4.88
OMW			Wd/Su	0.211			0.100	30.00	6.33			0.200	90.00	18.98
OMN			None	0.539			0.800	240.00	129.30			0.700	315.00	169.70
OSP		Small	Plant	0.055		0.200	0.200	20.00	1.11		0.100	0.200	15.00	0.83
OSW			Wd/Su	0.091			0.100	10.00	0.91			0.100	7.50	0.68
OSN			None	0.104			0.700	70.00	7.26			0.700	52.50	5.44
Total								1000.00	375.78				1000.00	344.90

Figure 1. Dendrograms of the significant clusters for a) habitat associations (H) and b) species (S) obtained with the clustering method based on the Orloci information metric. The cluster axis scale is χ^2 (127 d.f. for habitat and 65 d.f. for species). The cluster numbers correspond to the row (S) and column (H) numbers in Table 3 and the species are identified in Table 4. Clusters above the p= 0.01 significance level are not shown.

a) Habitats



b) Species

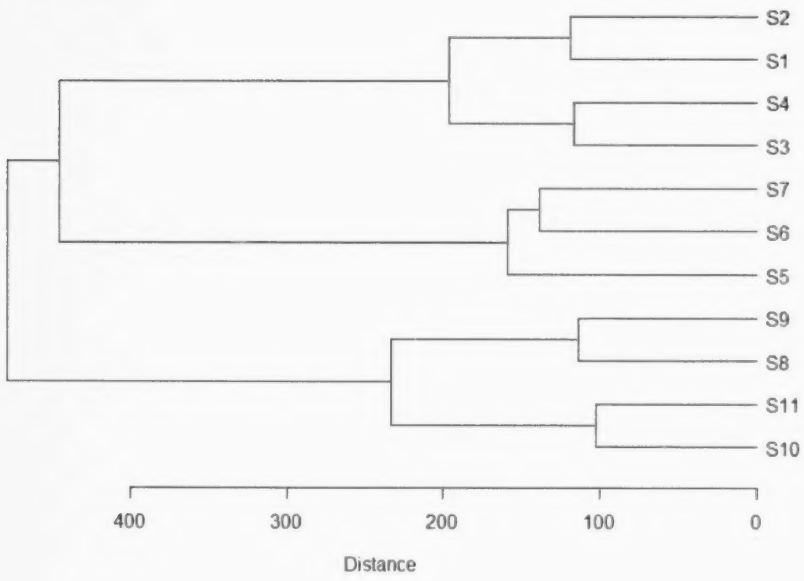


Figure 2. Bar graph showing the mean 1+ (hatched), mean SP (white), 1+ Cold×A2 (grey; salmonids and lampreys) and 1+ Warm×B (black; centrarchids, minnows, and bullheads) suitability values by habitat types. [In the three-letter habitat types, the first letter denotes flow - P (pool) or O (other); the second substrate – L (large), M (medium), or S (small); and the third cover – P (plant/algae), W (wood/substrate), or N (none)].

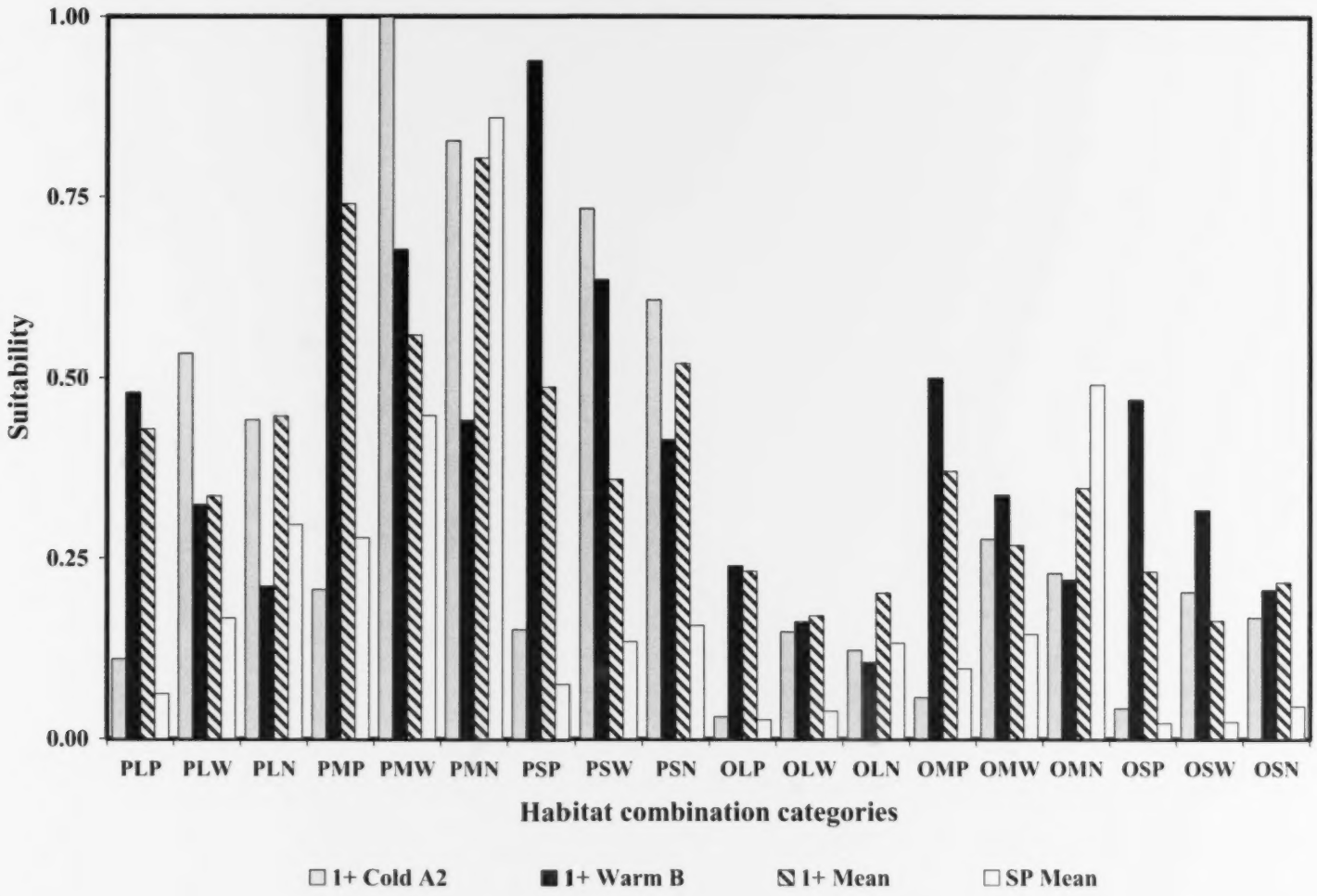
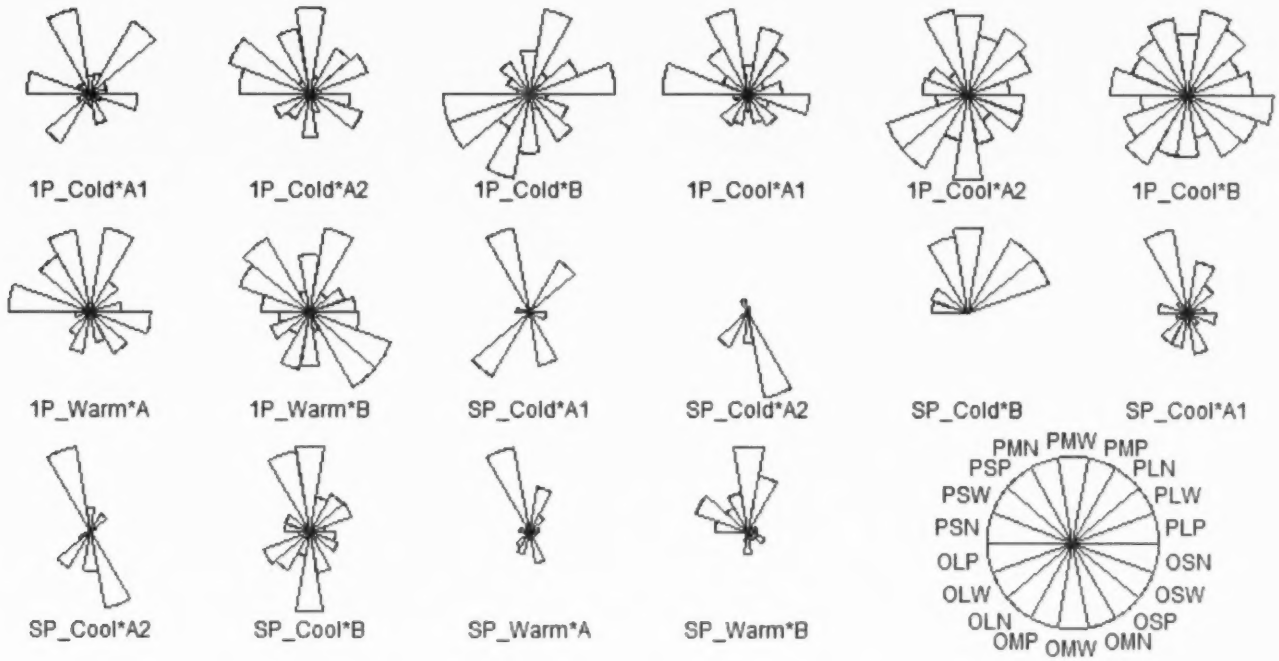


Figure 3. Star segment plots of the suitability of all 18 habitat types for all 16 fish-group x life-stage combinations. The key diagram, bottom right, identifies the habitat type combinations using the three letter labels described in Figure 2.



Appendix 1. Alphabetical list of species by common and Scientific name, included in this study.

Common name	*Latin name*	Common name	*Latin name*	Common name	*Latin name*
American Brook Lamprey	*Lampetra appendix*	Fathead Minnow	*Pimephales promelas*	Quillback	*Carpiodes cyprinus*
American Eel	*Anguilla rostrata*	Finescale Dace	*Phoxinus neogaeus*	Rainbow Darter	*Etheostoma caeruleum*
American Shad	*Alosa sapidissima*	Freshwater Drum	*Aplodinotus grunniens*	Rainbow Smelt	*Osmerus mordax*
Arctic Char	*Salvelinus alpinus*	Ghost Shiner	*Notropis buchanani*	Rainbow Trout	*Oncorhynchus mykiss*
Atlantic Salmon	*Salmo salar*	Gizzard Shad	*Dorosoma cepedianum*	Redfin Shiner	*Lythrurus umbratilis*
Banded Killifish	*Fundulus diaphanus*	Golden Redhorse	*Moxostoma erythrurum*	Redside Dace	*Clinostomus elongatus*
Bigmouth Buffalo	*Ictiobus cyprinellus*	Golden Shiner	*Notemigonus crysoleucas*	River Chub	*Nocomis micropogon*
Black Bullhead	*Ameiurus melas*	Goldfish	*Carassius auratus*	River Darter	*Percina shumardi*
Black Crappie	*Pomoxis nigromaculatus*	Grass Pickerel	*Esox americanus vermiculatus*	River Redhorse	*Moxostoma carinatum*
Black Redhorse	*Moxostoma duquesnei*	Greater Redhorse	*Moxostoma valenciennesi*	Rock Bass	*Ambloplites rupestris*
Blackchin Shiner	*Notropis heterodon*	Green Sunfish	*Lepomis cyanellus*	Rosyface Shiner	*Notropis rubellus*
Eastern Blacknose Dace	*Rhinichthys atratulus*	Greenside Darter	*Etheostoma blennioides*	Round Goby	*Neogobius melanostomus*
Blacknose Shiner	*Notropis heterolepis*	Hornyhead Chub	*Nocomis biguttatus*	Rudd	*Scardinius erythrophthalmu*
Blackside Darter	*Percina maculata*	Iowa Darter	*Etheostoma exile*	Ruffe	*Gymnocephalus cernuus*
Blackstripe Topminnow	*Fundulus notatus*	Johnny Darter	*Etheostoma nigrum*	Sand Shiner	*Notropis stramineus*
Bluegill	*Lepomis macrochirus*	Lake Chub	*Couesius plumbeus*	Sauger	*Stizostedion canadense*
Bluntnose Minnow	*Pimephales notatus*	Lake Chubsucker	*Erimyzon sucetta*	Sea Lamprey	*Petromyzon marinus*
Bowfin	*Amia calva*	Lake Sturgeon	*Acipenser fulvescens*	Shorthead Redhorse	*Moxostoma macrolepidotur*
Brassy Minnow	*Hybognathus hankinsoni*	Lake Whitefish	*Coregonus clupeaformis*	Silver Lamprey	*Ichthyomyzon unicuspis*
Bridle Shiner	*Notropis bifrenatus*	Largemouth Bass	*Micropterus salmoides*	Silver Redhorse	*Moxostoma anisurum*
Brindled Madtom	*Noturus miurus*	Least Darter	*Etheostoma microperca*	Silver Shiner	*Notropis photogenis*
Brook Silverside	*Labidesthes sicculus*	Logperch	*Percina caprodes*	Slimy Sculpin	*Cottus cognatus*
Brook Stickleback	*Culaea inconstans*	Longear Sunfish	*Lepomis megalotis*	Smallmouth Bass	*Micropterus dolomieui*
Brook Trout	*Salvelinus fontinalis*	Longnose Dace	*Rhinichthys cataractae*	Spoonhead Sculpin	*Cottus ricei*
Brown Bullhead	*Ameiurus nebulosus*	Longnose Gar	*Lepisosteus osseus*	Spotfin Shiner	*Cyprinella spiloptera*
Brown Trout	*Salmo trutta*	Longnose Sucker	*Catostomus catostomus*	Spottail Shiner	*Notropis hudsonius*
Burbot	*Lota lota*	Mimic Shiner	*Notropis volucellus*	Spotted Sucker	*Minytrema melanops*
Central Mudminnow	*Umbra limi*	Mooneye	*Hiodon tergisus*	Stonecat	*Noturus flavus*
Central Stoneroller	*Campostoma anomalum*	Mottled Sculpin	*Cottus bairdii*	Striped Shiner	*Luxilus chrysocephalus*
Channel Catfish	*Ictalurus punctatus*	Muskellunge	*Esox masquinongy*	Tadpole Madtom	*Noturus gyrinus*
Channel Darter	*Percina copelandi*	Ninespine Stickleback	*Pungitius pungitius*	Tessellated Darter	*Etheostoma olmstedi*
Chinook Salmon	*Oncorhynchus tshawytscha*	Northern Brook Lamprey	*Ichthyomyzon fossor*	Threespine Stickleback	*Gasterosteus aculeatus*
Cisco (Lake Herring)	*Coregonus artedii*	Northern Hog Sucker	*Hypentelium nigricans*	Trout-perch	*Percopsis omiscomaycus*
Coho Salmon	*Oncorhynchus kisutch*	Northern Madtom	*Noturus stigmosus*	Tubenose Goby	*Proterorhinus marmoratus*
Common Carp	*Cyprinus carpio*	Northern Pike	*Esox lucius*	Walleye (sander)	*Sander vitreus*
Common Shiner	*Luxilus cornutus*	Northern Redbelly Dace	*Phoxinus eos*	Warmouth	*Lepomis gulosus*
Creek Chub	*Semotilus atromaculatus*	Orangespotted Sunfish	*Lepomis humilis*	White Bass	*Morone chrysops*
Cutlips Minnow	*Exoglossum maxillingua*	Pearl Dace	*Margariscus margarita*	White Crappie	*Pomoxis annularis*
Eastern Sand Darter	*Ammocrypta pellucida*	Pink Salmon	*Oncorhynchus gorbuscha*	White Perch	*Morone americana*
Eastern Silvery Minnow	*Hybognathus regius*	Pugnose Minnow	*Opsopoeodus emiliae*	White Sucker	*Catostomus commersonii*
Emerald Shiner	*Notropis atherinoides*	Pugnose Shiner	*Notropis anogenus*	Yellow Bullhead	*Ameiurus natalis*
Fallfish	*Semotilus corporalis*	Pumpkinseed	*Lepomis gibbosus*	Yellow Perch	*Perca flavescens*
Fantail Darter	*Etheostoma flabellare*	Pygmy Whitefish	*Prosopium coulterii*		